Germination and Fertilization Regime Effects on the Growth of Container White Spruce Seedlings at Red Rock Research Station

by:

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ABSTRACT

To evaluate northern latitude conifer cultural regimes, white spruce (*Picea glauca* [Moench] Voss) was: a) germinated under three germination regimes (20/20°C under- and over-bench heating systems and 20/11°C under-bench heating system, all 12/12 h day/night) and then grown under a common cultural regime; or b) germinated ander a 20/20°C air temperature and fertilized with either a 20-8-20 grower formulation over the entire growing season, or a 20-20-20 Hi-Sol fertilizer until mid-July followed by a 10-52-17 finisher formulation. There were no significant differences in measured morphological characteristics or calculated seedling recovery between the heating systems at growing season end. Although the 20/20°C germination temperature nearly doubled germination heating costs over the split temperature 20/11°C treatment, seedling morphology and recovery were not improved. Under-bench heating costs in the fall were 30% less than those for over-bench heating to the same temperature setpoints. Seedlings produced under the 20-8-20 fertilizer regime were significantly shorter, sturdier, and greater in root mass than seedlings produced under the 20-20-20 plus 10-52-27 treatment. As a result of these experiments, modified germination temperature and fertilizer regimes will be incorporated into nursery culture at Red Rock Research Station.

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1 INTRODUCTION

The accelerated pace of non-satisfactorily stocked (NSR) backlog reforestation programmes in north central British Columbia challenges northern latitude nurseries to develop cultural techniques for producing cost-effective and high performance seedlings. Nursery research specific to the opportunities or limitations of northern latitude container seedling production in British Columbia is relatively scarce. This report describes experiments carried out at Red Rock Research Station (RRRS) near Prince George, British Columbia, which were designed to evaluate germination regimes and the effect of greenhouse heating system and fertilizer regimes on conifer seedling development.

A significant proportion of northern latitude nursery production costs are associated with greenhouse heating above ambient temperatures (Table1). The germination period, defined here as the 4 weeks following sowing, is a major component of total heating requirements. The first part of this study compares the costs and biological results of germination regimes that combine different air temperature setpoints and over- and under-bench forced air heating systems at RRRS (Lat. 53°45' N, Long. 122°41' W).

In northern latitude nurseries, the control of height growth to the specifications of the B.C. Forest Service, Silviculture Branch, is also a significant problem. The usual means of crop height control for these nurseries is by withholding water during the rapid growth phase (July) of the seedling (D'Aoust and Cameron 1981; Matthews 1981; Johnson 1985). This practice can have specific negative effects (D'Aoust and Cameron 1981; Johnson 1985; MacDonald and Owens 1988) and, more generally, may strongly limit the advantage of growing under long days at northern latitudes. It has also been suggested that, because containerized nursery seedlings are raised on luxurious levels of nutrients, better height control and more nutritionally balanced seedlings could be produced by significantly lowering these levels (W. Gates, Pers. comm., B.C. Forest Service, Silviculture Branch, Surrey, March, 1987). The second part of this report evaluates the effects of two fertilizer regimes and two greenhouse heating systems on the growth and development of white spruce (*Picea glauca* [Moench] Voss).

TABLE 1. Thirty-eight year monthly temperature records for Prince George Airport (Lat. 53°53' N, Long. 122°40' W) modified from Environment Canada (1981)

	Monthly temperature (°C)											
Code[a]	J	F	M	A	M	J	J	A	S	O	N	D
MDMx	-7.5	-1.0	3.6	10.3	16.1	19.5	22.0	20.8	15.9	9.6	0.9	-3.9
DEMx	12.8	12.8	17.8	29.7	32.2	33.9	34.4	33.3	28.9	25.0	16.1	11.7
MDMn	-16.6	-11.2	-7.2	-1.7	2.5	6.2	8.1	7.2	3.5	-0.1	-6.6	-11.9
DEMn	-50.0	-45.0	-37.8	-25.6	-8.3	-2.8	-1.7	-3.9	-12.2	-25.6	-41.7	-45.6
DM	-12.1	-6.1	-1.8	4.3	9.3	12.9	15.1	14.1	9.7	4.8	-2.9	-7.9
SD	4.6	3.7	2.4	1.7	1.1	1.4	1.1	1.4	1.4	1.4	3.5	4.3

[a] MDMx, mean daily maximum; DEMx, daily extreme of maximum; MDMn, mean daily minimum; DEMn, daily extreme of minimum; DM, mean daily temperature; and SD, standard deviation of mean daily temperature.

2 METHODOLOGY

2.1 Greenhouse Facilities

Seedlings were grown in three 6.5 x 12 m Harnois Nordique®[1] double poly greenhouses at RRRS equipped with Modine 149 400 British Thermal Units (BTU) furnaces and two Acme 5700 cubic feet per minute (cfm) exhaust fans and manual side walls. All houses have 400-W high-pressure sodium lamps for photoperiod extension, giving a minimum of 5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at styroblock level to prevent premature budset (Arnott and Mitchell 1981).

Fertilization, misting, and irrigation are supplied with Munckoff overhead travelling double booms. Fertilizer is applied in irrigation water using a Pulsa Series injector controlled by an electroconductivity loop. An ESC100/ESC50 (Energrated System Controls, Surrey, B.C.) control system was used to control all functions related to heating, venting, and fertilization, including misting and irrigation in the greenhouses. This was upgraded in mid-season to an Access 2000 ESC system.

2.2 Stock and Sowing

Seed from B.C. Forest Service registered white spruce seedlot 4073 (Hungary Creek, 93 H 14, 1190 m a.s.l.) was sown at RRRS on 18 March 1987, in BCFS/CFS PSB 313a polystyroblocks (Beaver Plastics, Edmonton, Alta.) at a density of 198 cavities per block (947 cavities m^{-2}). The rooting medium was composed of two parts peat to one part vermiculite (v:v) with 12-mesh lime and Osmocote ® (18-6-12, N-P-K), at rates of 2 and 6.5 $kg \cdot m^{-3}$ of peat vermiculite mix, respectively. Seeds were covered with a fine layer of forestry sand. Standard misting procedures (Matthews 1983) were carried out during the germination period. High-pressure sodium lamps were used to extend the photoperiod to approximately 23 hours from time of sowing until June 11, after which the crop was grown under ambient photoperiod. Crop watering practice followed Matthews (1981, 1983) Drought stress was not used as a means of controlling crop height. The crop was grown on a 1-year (March 18 - November 02) rotation.

2.3 Treatments

Three cultural factors influencing container conifer production are considered in this experiment: 1) greenhouse air temperature throughout the germination period (March 18 - April 21); 2) type of forced air heating system used throughout the germination period; and 3) the post-germination fertilizer regime.

Air temperatures of 20/20°C and 20/11°C (12/12 hour day/night) were tested. These represent both the presumed optimum for germination, and the operational temperatures normally experienced in double poly greenhouses at northern latitude nurseries, regardless of the setpoints trying to be maintained. The temperature range also represents a significant range of energy costs. Two heating systems were tested: an under-bench unskirted forced air system and an over-bench system. Post-germination period (20/20° C under-bench) fertilizer regimes tested included a "grower-finisher" 20-20-20 N-P-K Hi-Sol followed by 10-52-17 (Green Valley Fertilizers Ltd., Surrey, B.C. V3W 3A8), and a "grower" 20-8-20 N-P-K "Forestry Seedling Special" (Plant Products Fertilizer Ltd., Bramalea, Ont. L6T 1G1). These are referred to as the 20-20-20 and 20-8-20 treatments, respectively.

Further details of the cultural regimes are given in Table 2. Different levels of these three cultural factors were combined into five experimental treatments (Table 3). Treatments 1, 4, and 5 were germinated and grown in separate greenhouses. Treatments 2 and 3 resulted from a post-germination reciprocal transfer of polystyroblocks from treatments 1 and 4, respectively.

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[1] Use of a product name does not constitute an endorsement by the B.C. Forest Service.

TABLE 2. Description of cultural regime from April 21 (post-germination) until November 2 (time of lift) at Red Rock Research Station. (± N ppm) indicates the approximate application rate of nitrogen.

	Day/night		Fertilizer		
Date	Temperature °C	Duration h	20-20-20	20-8-20	±N ppm
21 April	21/13	16/8	20-20-20	20-8-20	120
11 June	17/10	16/8	20-20-20	20-8-20	60
20 June	17/08	16/8	20-20-20	20-8-20	60
24 July	17/07	16/8	10-52-17	20-8-20	60
			TRACE ELEMENT MIX[a] ADDED FROM THIS POINT ON		
17 August	17/06	16/8	10-52-17	20-8-20	50
05 October	13/03	13/11	10-52-17	20-8-20	50
15 October	09/02	12/12	10-52-17	20-8-20	50

[a] Plant-Prod Chelated Trace Element Mix (Plant Products Fertilizers Ltd., Bramalea, Ont., L6T 1G1) at a rate of 0.75 g/L of stock solution diluted ~100-fold for delivery to the crop. Guaranteed product analysis: Fe 7%, Mn 2%, Zn 0.4%, Cu 0.1%, B 1.3%, Mo 0.06%.

TABLE 3. Description of experimental treatments by germination air temperature,[a] heating system,[b] and fertilizer regime,[c] specifying *a priori* contrasts. (*) signifies contrasts orthoganal within themselves; df = degrees of freedom.

		Treatments				
Contrast	df	1 20/20°C under-b. 20-20-20	2 20/20°C over-b. 20-20-20	3 20/20°C under-b. 20-8-20	4 20/20°C over-b. 20-8-20	5 20/11°C under-b. 20-20-20
Germination temperature effect	1	1	0	0	0	-1
Heating system effect at 20/20°C	1	1	-1	0	0	0
Fertilizer effect*	1	1	1	-1	-1	0
Heating system effect*	1	1	-1	1	-1	0
Heating by fertilizer interaction*	1	1	-1	-1	1	0

[a] Germination air temperature 20/20°C or 20/11°C.
[b] Heating system under-bench (b.) or over-bench.
[c] Fertilizer regime 20-20-20 or 20-8-20.

2.4 Measurements

2.4.1 Greenhouse environment

Records were kept of average greenhouse air temperature at seedling height, block soil temperatures, total heating hours, and heater stop/starts from March 18 to April 21. Ambient climatic conditions during this period were typical (Table 1), ranging from –2° to 4°C for mean daily temperature, and with night minimums as low as –7°C. Maintaining day/night greenhouse temperatures of 20/20 or 20/11 under such ambient conditions is energy-demanding.

The computer control system was programmed to regulate the minimum air temperature closely and the maximum temperature loosely, provided the latter was above the day setpoint.

Night temperatures lower than the setpoint resulted if the heating system could not maintain the setpoint under low ambient night temperature conditions.

During the fall phase of crop growth (September 21 - November 2), when heating was used to maintain minimum night air temperature setpoints to prevent freezing, a further series of comparisons was made of the efficiency of over- and under-bench heating systems.

2.4.2 Seedlings

Crop growth was assessed periodically to provide growth curves of height, caliper, shoot mass, and root mass over time within treatments, as well as to derive shoot to root ratios and sturdiness ratios (height [mm] divided by caliper [mm]).

A single sample consisted of 20 seedlings, with 1 selected systematically from each of 20 blocks for each treatment. On the 175th day following germination (September 8), five blocks were randomly selected from each treatment and 40 seedlings sampled from each block to calculate operational inventories. Twenty seedlings were randomly selected from the 200 to provide the day 175 growth curve estimates. This day 175 inventory was the only deviation from the normal sampling protocol.

Foliar samples were taken from the two fertilizer treatments at roughly 2-week intervals from late July to early November. Bulked samples of 16 seedlings were analysed at Norwest Soil Research Inc. for macro- and micronutrient concentrations.

2.4.3 Analysis

Seedling growth data were first considered graphically over the growing season, and then statistically by a fixed effect, one-way replicated analysis of variance of seedling morphology at season end (November 2). Single degree of freedom linear contrasts were specified *a priori* (Table 3) and tested at $\alpha = 0.05$ using Proc GLM (SAS Institute Inc. 1985).

The germination temperature effect contrast (Table 3) compares 20/20°C germination air temperatures in the presence of common under-bench heating and 20-20-20 fertilizer treatments. The heating system effect at 20/20°C contrasts under- and over-bench heating systems at common germination temperatures and fertilizer regimes. Both contrasts are discussed in Section 3.1. The fertilizer effect and heating system effect contrasts (Table 3) test the significance of these factors at a common 20/20°C germination temperature. Finally, the interaction contrast tests heating system and fertilization treatment main effect interactions at a common 20/20°C germination temperature. The latter three contrasts are discussed in Section 3.2.

Greenhouse environmental data, equipment start/stops, and run time totals are presented graphically. As there is no replication in this data, no significance testing was carried out.

3 RESULTS AND DISCUSSION

For ease of presentation, this section first discusses comparisons of germination regime data (treatments 1, 2, and 5 [Table 3]), and then the heating system and fertilizer regime results (treatments 1-4 [Table 3]).

3.1 Comparison of Germination Regimes

3.1.1 Heating costs

Germination heating costs are directly related to heater run times. Trying to maintain 20/20°C air temperatures (with either under- or over-bench heating) in double poly greenhouses increased heating costs by nearly 100% over the 20/11°C split temperature treatment (Figure 1). The under-bench heated greenhouses cycled more slowly around temperature setpoints than the over-bench heated house, and resulted in 20% fewer equipment stop/starts (Figure 2). Fewer starts and the same number of heating hours for a 20/20°C under-bench heating system make it more efficient than an over-bench system, at the same temperature. However, the most cost-effective germination temperature regime was with the 20/11°C under-bench system, which had both substantially lower heating hours and fewer stop/starts.

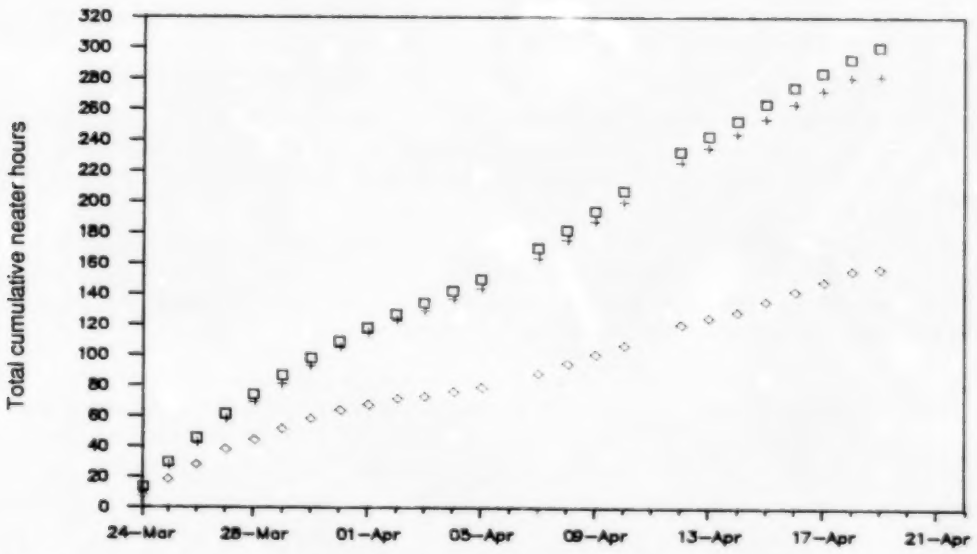

FIGURE 1. Greenhouse heater fan run time totals during the 1987 germination period for 20/20°C under-bench (□), 20/20°C over-bench (+), and 20/11°C under-bench (◊) forced air systems at Red Rock Research Station.

The costs of treatments may differ if soil temperature, or a combination of soil temperature and seedling level air temperature, is used as the controlling variable rather than seedling level air temperature alone. Figure 3 (a, b and c) compares the differences between styroblock soil temperature and seedling height air temperature for the three temperature and heating system combinations. Maximum differences between the two measurements occured post-dawn in the 20/20°C treatments (Figure 3a, and b), when soil temperatures averaged 2°C lower than air temperatures (20 - 18°C). However, differences in the 20/11°C treatment (Figure 3c) were minimal at the 11°C night setpoint.

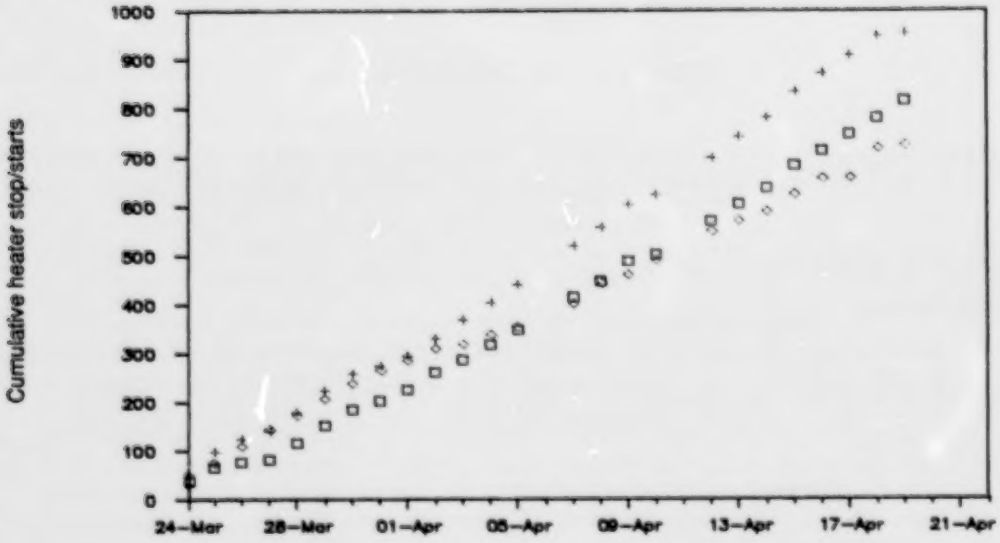

FIGURE 2. Greenhouse heater fan stop/start totals during the 1987 germination period for 20/20°C under-bench (□), 20/20°C over-bench (+), and 20/11°C under-bench (◊) forced air systems at Red Rock Research Station.

Soil temperature lagged considerably behind air temperature during the day, often requiring 12 hours to reach air temperature setpoints (Figure 3a, b, and c). No significance is ascribed to under- versus over-bench heating systems in terms of the differences between measured air and soil temperatures.

During the fall phase of crop growth, when heating was used only to maintain the minimum night setpoints, the under-bench heating system consumed 30% less fuel and had almost 30% fewer start/stops than did the over-bench system (Table 4). These data clearly indicate that under-bench heating was more cost-effective than over-bench during this period.

TABLE 4. Comparison of heater run time totals and stop/starts in over- and under-bench heating systems, during the fall (mid-September until November 1). Heaters were run to prevent freezing night temperatures in the greenhouses at Red Rock Research Station.

System	Total hours	Percent	Total stop/starts	Percent
Under-bench	90.4	69	662	72
Over-bench	131.3	100	922	100

The difference between the spring and fall heating system comparison may be due to the mid-season installation of a more responsive computer controller. However, this does not alter the overall cost perspective. In fact, it suggests that spring under-bench savings would have been even greater had the new system been in place at that time. Similarly, under-bench heating with the use of skirted benches would probably have resulted in even greater relative cost savings.

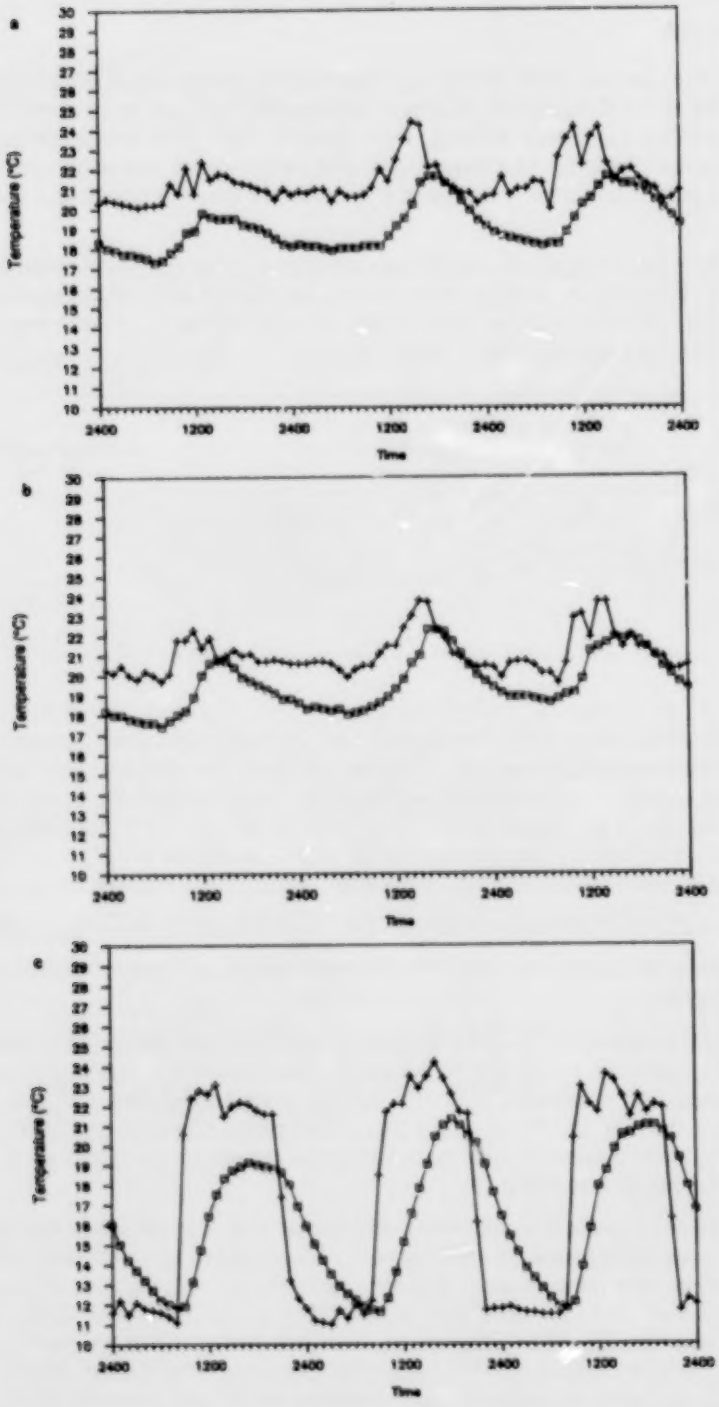

FIGURE 3. Typical diurnal air (+)and soil (□) temperature patterns for **a**, 20/20°C under-bench; **b**, 20/20°C over-bench; and **c**, 20/11°C under-bench regimes during germination at Red Rock Research Station.

3.1.2 Seedling growth

The rate of germination and early growth was observed to be greater in the 20/20°C under-bench treatment than in the 20/11°C treatment. However, differences between heating systems at the same temperature, 15 and 20 days after sowing, were greater than differences between germination temperature treatments (Table 5). The lowest temperature treatment was within 3% of the expected 72% germination total, 20 days after sowing and 8 days before thinning (Table 5).

TABLE 5. Germination percentages 15 and 20 days after sowing, by germination temperature treatment. Values are the mean of 99 cavities sampled in each of two blocks per treatment. Expected germination is taken from the B.C. Forest Service Tree Seed and Inventory System Seedlot Report, October 1987.

Treatment	Percent germination		Expected germination
	Day 15	Day 20	
20/20°C under-bench	52	60	72
20/20°C over-bench	61	70	72
20/11°C under-bench	48	69	72

Seasonal growth data are presented in Figures 4-8. Rate of height growth tended to be least with the 20/11°C germination regime (Figure 4). The low values at day 175 are ascribed to the different sampling procedure at that time (see Section 2.4.2). None of the stock was over maximum height (25 cm), but all exceeded target height (17 cm) by as little as 28% for 20/11°C treatment and as much as 41% for 20/20°C under-bench treatment (Table 6). The best degree of height control was observed in the split germination temperature regime, and was thought to have resulted because;

1) canopy closure occurred relatively later in this treatment than in the others; and
2) cultural decisions made on the 20/20°C crop both anticipated and controlled the 20/11°C crop growth response.

Early in the growing season, both 20/20°C germination treatments tended to produce larger caliper seedlings (Figure 5). However, by the end of the season the treatment range was just over 5% (Table 6). All treatments exceeded minimum caliper (2.4 mm) by early August (day 140) and achieved target caliper (3.0 mm) by time of lift. Shoot mass increased more slowly in the 20/11°C germination treatment than in the other treatments until quite late in the growing season (Figure 6). End of season shoot mass treatment range was about 5%.

Root mass increment showed no treatment effect until mid- August, when the split temperature germination treatment exceeded the others (Figure 7). This relationship continued until the end of the season, after which all root masses were greater than 575 mg and the root mass of the 20/11°C treatment exceeded this value by more than 40% (Table 6). Shoot to root ratios were smaller in seedlings germinated under the 20/11°C temperature regime at the end of the growing season (Table 6), mainly because of the increased 20/11°C treatment root mass. This finding may be very important for northern latitude seedling nurseries, where relatively small root masses of 350 - 550 mg are considered normal (E. Van Eerden, Pers. comm., B.C. Forest Service, Silviculture Branch, Victoria, Dec. 1987). Such small root masses may be detrimental to early field performance (Thompson 1985).

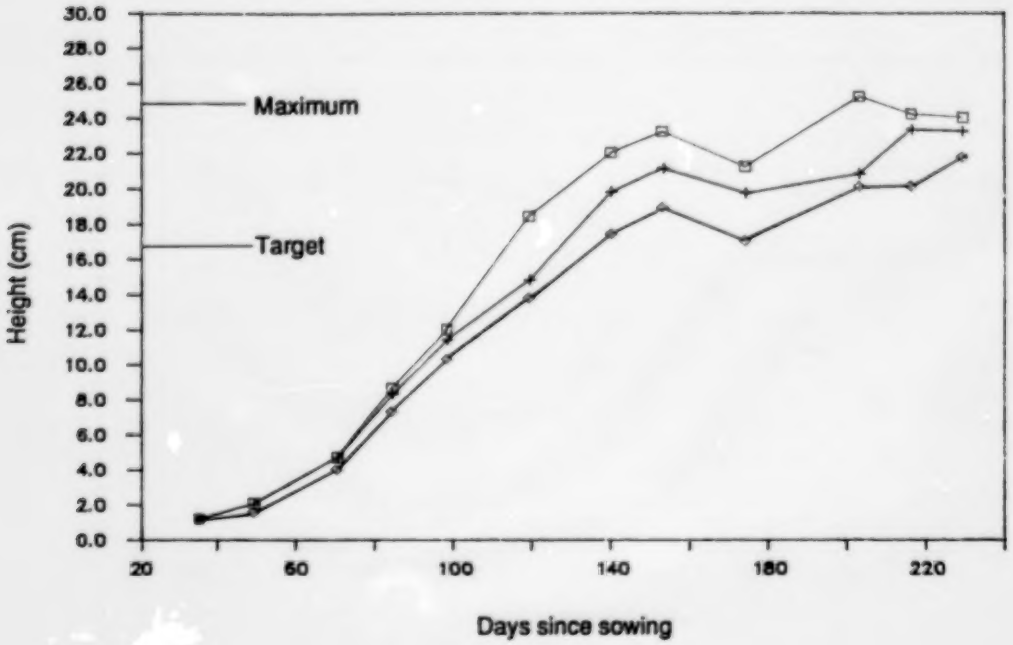

FIGURE 4. Cumulative mean height of interior spruce grown at a common regime, but germinated under 20/20°C under-bench (□), 20/20°C over-bench (+), and 20/11°C under-bench (◊) temperature regimes at Red Rock Research Station. Each point is the mean of 20 seedlings. Also shown are B.C. Forest Service target and maximum height specifications for this crop.

TABLE 6. Seedling morphology means and standard deviations (bracketed), by treatment[a] at end of season (November 2). Sturdiness ratio = height (mm)/caliper (mm); n = 20.

	Morphological variable					
Treatment[a]	Height (mm)	Caliper (mm)	Shoot mass (mg)	Root mass (mg)	Shoot/root ratio	Sturdiness ratio
1	240 (60.0)	3.1 (0.55)	2 177 (918.3)	622 (398.4)	3.9 (1.00)	78 (11.8)
2	232 (65.2)	2.9 (0.57)	2 044 (971.5)	575 (307.0)	3.8 (0.82)	79 (15.7)
3	218 (66.2)	3.1 (0.50)	2 012 (732.3)	701 (348.9)	3.1 (0.98)	69 (15.5)
4	196 (37.6)	3.2 (0.45)	1 966 (529.8)	866 (386.8)	2.6 (0.80)	63 (12.2)
5	217 (52.8)	3.1 (0.30)	2 067 (660.3)	810 (288.2)	2.7 (0.61)	69 (15.2)

[a] 1 - 20/20°C, under-bench, 20-20-20 fertilizer
2 - 20/20°C, over-bench, 20-20-20 fertilizer
3 - 20/20°C, under-bench, 20-8-20 fertilizer
4 - 20/20°C, over-bench, 20-8-20 fertilizer
5 - 20/11°C, under-bench, 20-20-20 fertilizer

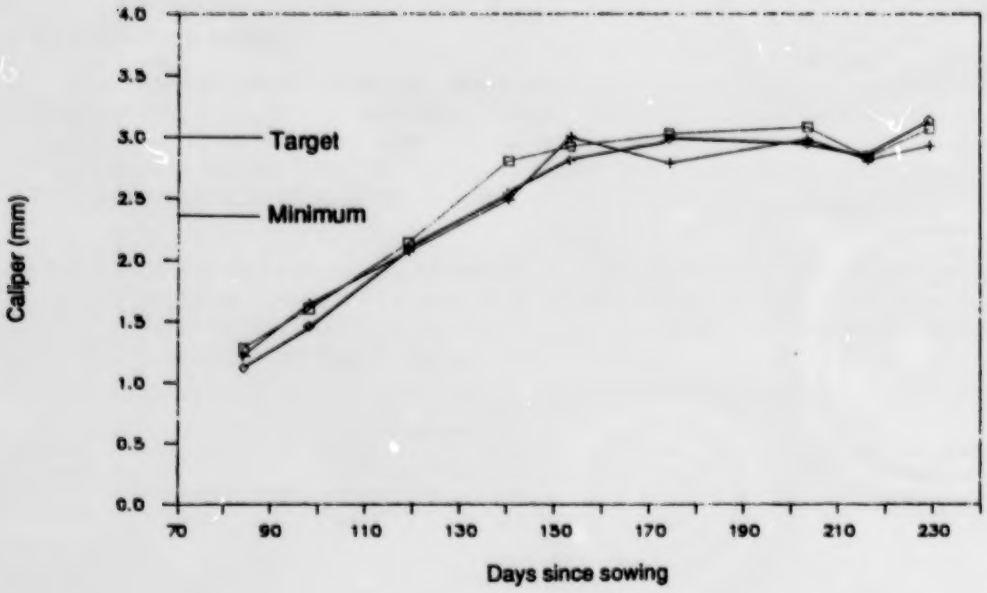

FIGURE 5. Cumulative mean caliper (root collar diameter) of interior spruce grown at a common cultural regime, but germinated under 20/20°C under-bench (□), 20/20°C over-bench (+), and 20/11°C under-bench (◊) temperature regimes at Red Rock Research Station. Each point is the mean of 20 seedlings. Also shown are B.C. Forest Service target and minimum caliper specifications for this crop.

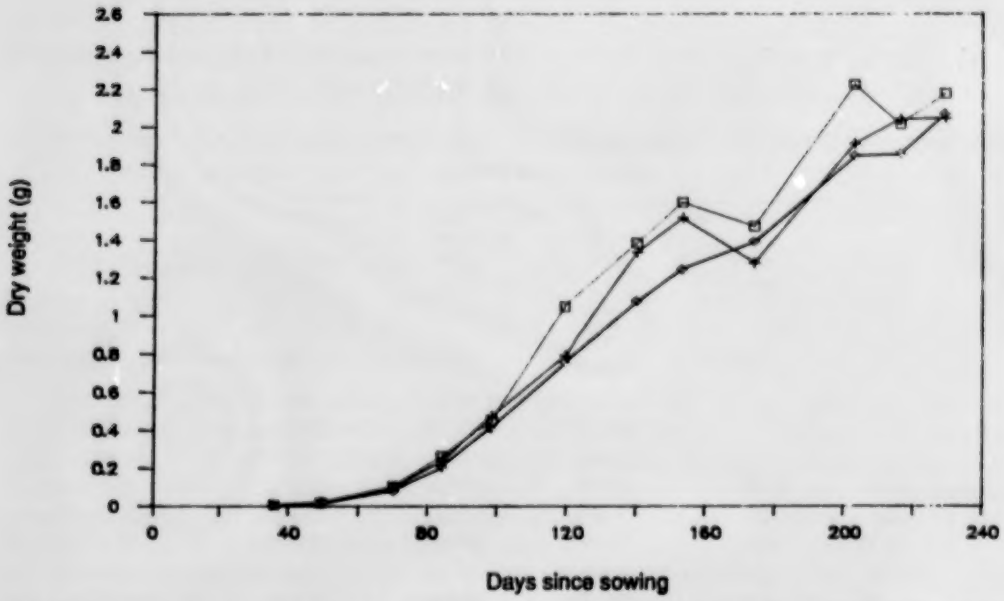

FIGURE 6. Cumulative mean shoot mass of interior spruce grown under a common cultural regime, but germinated at 20/20°C under-bench (□), 20/20°C over-bench (+), and 20/11°C under-bench (◊) temperature regimes at Red Rock Research Station. Each point is the mean of 20 seedlings.

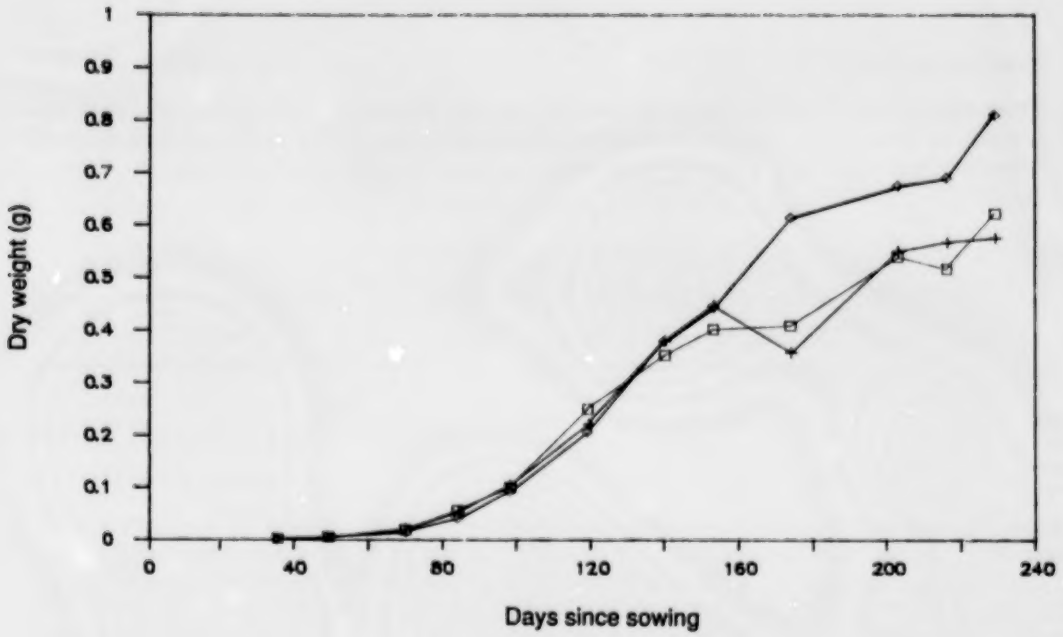

FIGURE 7. Cumulative mean root mass of interior spruce grown under a common cultural regime, but germinated at 20/20°C under-bench (□), 20/20°C over-bench (+), and 20/11°C under-bench (◊) temperature regimes at Red Rock Research Station. Each point is the mean of 20 seedlings.

Drought stress was not used to control height in this experiment. This allowed root mass to continue to increase during a period when it would normally be limited by the withholding of moisture (July to early August, days 106 to 140). In addition, all cultural decisions, such as turning off lights and altering growing temperature regimes and fertilizer formulations, were based on the requirements of seedlings in the fastest growing treatment. This was probably more effective in controlling the growth of the 20/11°C treatment seedlings than the more developmentally advanced seedlings in the other two germination treatments. The 20/11°C treatment seedlings closed canopy later and were shorter and woodier. These characteristics may have resulted in the entire shoot contributing to carbohydrate production, or at least in reducing the maintenance demand of the lower shoot. This was not the case for seedlings from the faster developing 20/20°C treatments. Late in the season the lower portions of these shoots may have been significant consumers of carbohydrates, and thus may have potentially limited allocation of carbon to roots (see Hawkins *et al.* 1987).

The practical significance of this may be that seedlings with greater root mass and reduced height will be able to occupy a larger soil volume in a shorter period of time, tolerate the shedding of more roots in cold soils without deleterious effects, and withstand outplanted stress periods better (Draper *et al.* 1985). The early performance of these treatments will be assessed in subsequent field trials.

Single degree of freedom linear contrasts of heating system effect at a common 20/20°C temperature, and germination temperature effect under a common type of heating system, were nonsignificant for all variables tested (Table 7) at season end.

3.1.3 Seedling recovery

Estimated seedling recoveries to B.C. Forest Service shipping standards are given in Table 8. There was no difference in recovery among the three treatments. The majority of culls in the 20/20°C germination treatments were caliper-related, while insufficient height was the primary reason for culling in the 20/11°C treatment.

TABLE 7. Treatment contrast F values and probability of F occurring by chance (bracketed) by morphological variable at end of season (November 2). (*) signifies contrasts orthoganal within themselves.

Contrast	Height	Caliper	Shoot mass	Root mass
Germination temperature	1.60 (0.21)	0.24 (0.63)	0.20 (0.65)	2.92 (0.09)
Heating system effect at 20/20°C	0.20 (0.66)	0.84 (0.36)	0.24 (0.63)	0.20 (0.65)
Fertilizer*	5.28 (0.02)	1.86 (0.18)	0.48 (0.49)	5.65 (0.02)
Heating* System	1.41 (0.24)	0.27 (0.61)	0.27 (0.61)	0.57 (0.45)
F x HS Interaction*	0.29 (0.59)	0.63 (0.43)	0.06 (0.80)	1.85 (0.18)

TABLE 8. Percentage recovery of shipable seedlings at inventory (September 8) resulting from germination air temperature and heating system treatments. This is based on a 200-tree sample, with 40 trees selected from each of five blocks. Total percentage of trees culled and the reason for culling are given. Cull percentages and recovery percentage may not add up to 100 because of rounding.

		Percentage trees culled			
Treatment	Recovery %	Below caliper	Below height	Below caliper and height	Below caliper for above target height
20/20°C under-bench	82	15	1	1	2
20/20°C over-bench	85	12	0	3	1
20/11°C under-bench	82	6	9	3	1

3.1.4 Conclusions

This study has shown that 20/20°C germination air temperature regimes, although significantly increasing germination heating costs over the 20/11°C regime, did not:

1. provide a better economic recovery through increased seedling numbers; or
2. produce significantly different seedlings at time of lift in the nursery.

In fact, the least expensive germination heating option may have produced the "best quality" seedlings based on trends in treatment relative root mass and seedling height. Greater energy savings and equipment use efficiency were associated with the under-bench 20/11°C treatment. During the fall, before lift, under-bench forced-air heating was about 30% more cost-effective in maintaining night temperature setpoints than was over-bench heating.

3.2 Heating System and Fertilizer Regime

3.2.1 Seedling growth

Treatments 1-4 (Table 3) are a 2 by 2 factorial in heating system and fertilizer regime. Cumulative mean height curves (Figure 8) show that by the end of the growing season (November 2), all treatment means were above target and below maximum height standards as specified by the B.C. Forest Service for this crop. Treatment separation was consistent from the 140th day following sowing (August 5, 1987) (Figure 8). This corresponds with the change from 20-20-20 Hi-Sol to 10-52-17 (Table 2) and is further demonstated by the continued separation in P foliar concentration between the two fertilizer treatments (Table 9).

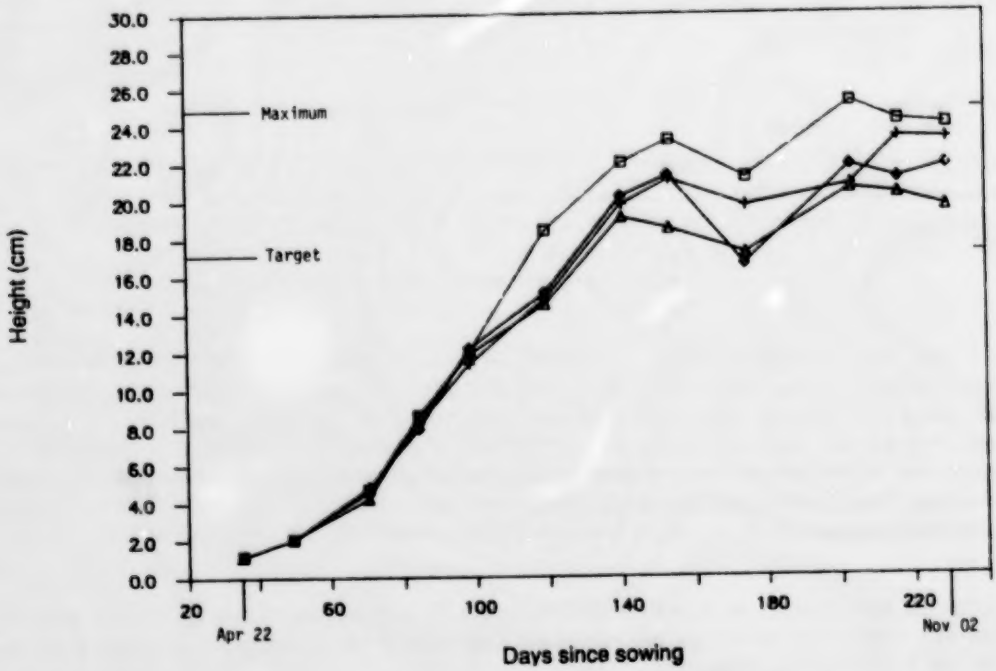

FIGURE 8. Cumulative mean height by heating system and fertilizer treatment 1 (under-bench + 20-20-20) (□), 2 (over-bench + 20-20-20) (+), 3 (under-bench + 20-8-20) (◊), and 4 (over-bench + 20-8-20) (Δ) over the growing season at Red Rock Research Station. Each point is the mean of 20 seedlings. Also shown are B.C. Forest Service target and maximum height specifications for this crop.

Phosphorus levels in the 20-8-20 treatment were approximately 30% lower than the 20-20-20 plus 10-52-17 treatment from late July through early November. Micronutrient differences between treatments were slight (Table 9). The lower zinc levels associated with high phosphorus concentrations are consistent with results reported by Loneragan *et al.* (1979). Foliar zinc levels were still within the optimum range accepted for forest seedling cultures (Norwest Soil Research Inc., Langley, B.C.).

TABLE 9. Seasonal change in foliar macro- and micronutrient concentration for the grower-finisher (20-20-20, then 10-52-17) and the grower (20-8-20) fertilizer treatments. Rate is the rate of N applied (ppm). See Table 2 for seasonal cultural description.

Date	Fertilizer treatment	Rate	Macronutrient %					
			N	P	K	Ca	Mg	S
23 July	20-20-20	(60)	3.2	0.42	1.20	0.70	0.24	0.11 [a]
	20-8-20	(60)	3.0	0.37	1.30	0.68	0.26	0.13
15 August	10-52-17	(60)	3.3	0.52	0.94	0.75	0.25	0.12
	20-8-20	(60)	3.1	0.40	1.00	0.72	0.25	0.14
01 September	10-52-17	(50)	3.2	0.57	1.10	0.94	0.25	0.12
	20-8-20	(50)	2.9	0.40	1.10	1.00	0.23	0.14
13 October	10-52-17	(50)	3.0	0.58	0.93	0.95	0.24	0.12
	20-8-20	(50)	2.8	0.42	0.90	0.88	0.22	0.19
02 November	10-52-17	(50)	2.7	0.53	0.89	0.90	0.23	0.13
	20-8-20	(50)	2.8	0.41	0.89	0.78	0.22	0.15

Date	Fertilizer treatment	Rate	Micronutrient ppm				
			Fe	Cu	Zn	Mn	B
23 July	20-20-20	(60)	140	7	26	416	11 [a]
	20-8-20	(60)	150	9	43	540	14 [a]
15 August	10-52-17	(60)	470 [b]	7	47	435	26
	20-8-20	(60)	200	6	52	416	24
01 September	10-52-17	(50)	170	4	42	432	23
	20-8-20	(50)	170	5	49	433	23
13 October	10-52-17	(50)	132	4	50	320	20
	20-8-20	(50)	164	5	64	380	22
02 November	10-52-17	(50)	133	4	53	425	14 [a]
	20-8-20	(50)	155	20 [b]	73	455	21

[a] indicates deficiency (Norwest Soil Research Inc., Langley, B.C.)

[b] no explanation offered for these values

Seedlings averaged 30mm less in height under the 20-8-20 regime (Table 6). This is consistent with the hypothesis that seedlings are raised on luxurious levels of nutrients, and that decreased nutrition can aid in crop height control.

There were no apparent treatment differences among caliper (Figure 9) or shoot mass (Figure 10) seasonal growth curves. The 20-8-20 treament had 30% greater root mass at season end (Table 6), largely attributable to increased fall growth rates (Figure 11).

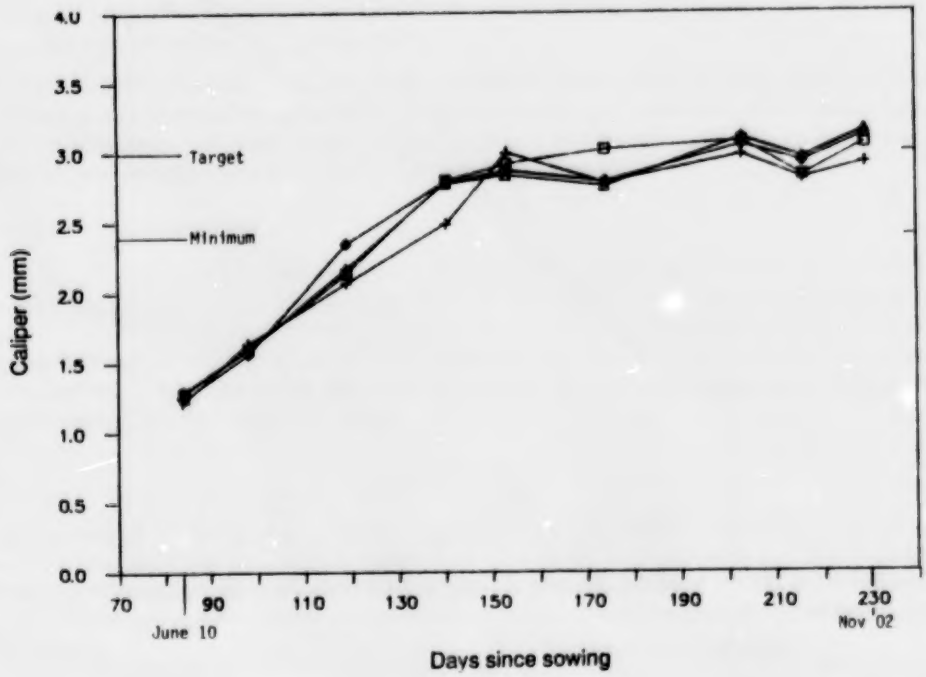

FIGURE 9. Cumulative mean caliper (root collar diameter) by heating system and fertilizer treatment 1 (under-bench + 20-20-20) (□), 2 (over-bench + 20-20-20) (+), 3 (under-bench + 20-8-20) (◊), and 4 (over-bench + 20-8-20) (Δ) over the growing season at Red Rock Research Station. Each point is the mean of 20 seedlings. Also shown are B.C. Forest Service target and minimum caliper specifications for this crop.

Carbohydrate allocation to roots generally comes after shoot demands have been met (Hawkins *et al.* 1987). In the relatively dense PSB 313a polystyroblocks (947 cavities m^{-2}), the faster rate of 20-20-20 shoot extension (Figure 8) resulted in early canopy closure when compared to that of the 20-8-20 treatment. Carbohydrate production in the 20-20-20 treatment may also have been required for lower shoot maintenance reactions because of the low light levels and possible negative carbon balance of these tissues. This would have the effect of lowering the 20-20-20 treatment root mass allocation, but not influencing shoot mass, and thus it would decrease the shoot/root mass ratio (Table 6).

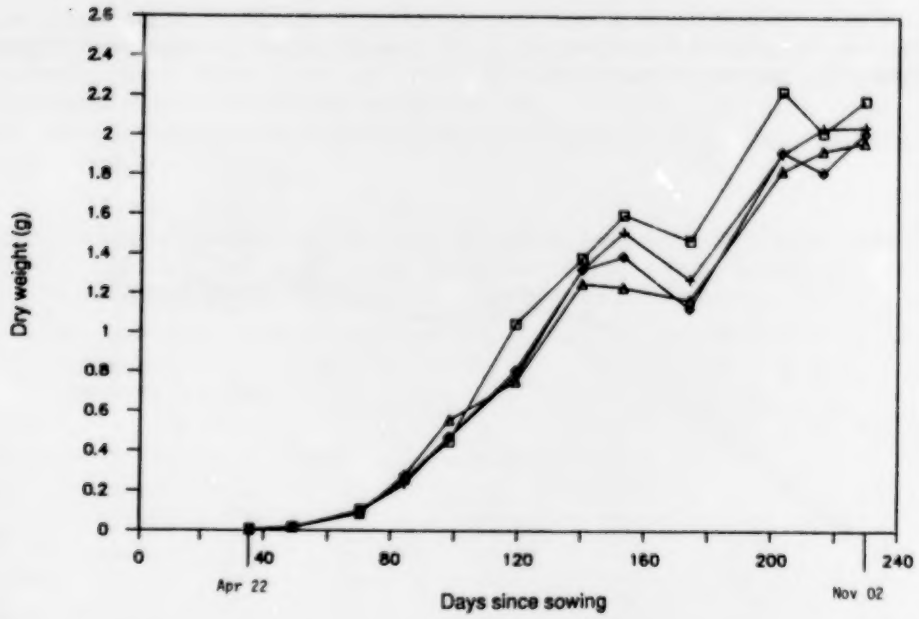

FIGURE 10. Cumulative mean shoot mass by heating system and fertilizer treatment 1 (under-bench + 20-20-20) (□), 2 (over-bench + 20-20-20) (+), 3 (under-bench + 20-8-20) (◊), and 4 (over-bench + 20-8-20) (Δ) over the growing season at Red Rock Research Station. Each point is the mean of 20 seedlings.

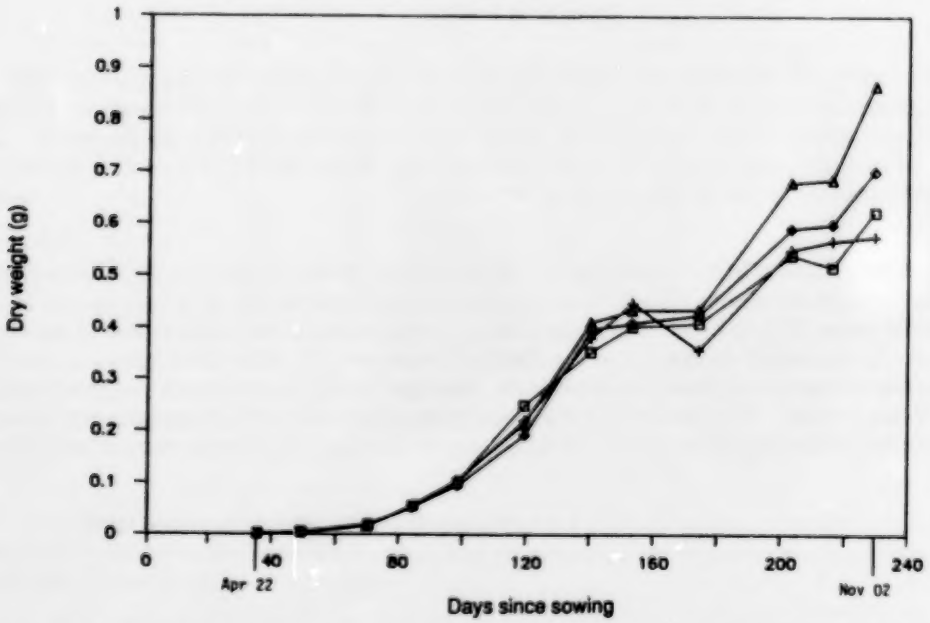

FIGURE 11. Cumulative mean root mass by heating system and fertilizer treatment 1 (under-bench + 20-20-20) (□), 2 (over-bench + 20-20-20) (+), 3 (under-bench + 20-8-20) (◊), and 4 (over-bench + 20-8-20) (Δ) over the growing season at Red Rock Research Station. Each point is the mean of 20 seedlings.

The sturdiness ratio (seedling height/seedling caliper) was variable during the season, but at the season end seedlings from the 20-8-20 treatment were sturdier (Table 6).

Burdett *et al.* (1984) reported that outplanted interior spruce would grow little in height until this ratio was in the region of 40-50. Once this was achieved, "planting check" ended and height and diameter growth increased proportionally. Presumably, the closer the nursery ratio is to this, the less time the tree will spend in "planting check."

Statistical contrasts of overall heating system effect (Table 7) were non-significant for end of season seedling morphology, and there was no significant interaction with fertilizer regime. Fertilizer effects at season end were significant for root mass and height (Table 7), as suggested by Figures 8 and 11, and also by treatment morphology means (Table 6).

3.2.2 Seedling recovery

Seedling recoveries determined on September 8 are given in Table 10 and indicate a slightly better overall return from the 20-8-20 fertilizer treatment. Most seedlings failing to meet shipping specifications in the 20-20-20 treatment did so because of insufficient caliper. This was also the primary reason for culling in the 20-8-20 treatment, but the numbers culled for caliper alone were less than half that recorded in the 20-20-20 treatment. All total recoveries were well above operational expectations (75% for this stocktype).

TABLE 10. Percentage recovery of shipable seedlings at inventory (September 8) resulting from heating system and fertilizer treatments. This is based on a 400-tree sample, with 40 trees selected from each of 10 blocks. Total percentage of trees culled and the reason for culling are given. Cull percentages and recovery percentage may not add up to 100 because of rounding.

		Percentage trees culled			
Treatment	Recovery	Below caliper	Below height	Below caliper and height	Below caliper for above target height
20-20-20 under-bench	82	15	1	1	2
20-20-20 over-bench	85	12	0	3	1
20-8-20 under-bench	90	6	1	4	0
20-8-20 over-bench	91	6	1	2	1

3.2.3 Conclusions

Over- or under-bench heating systems controlling air temperature over the germination period did not significantly influence measured seedling morphology at the end of the 1987 growing season. Fertilizer regime had a significant effect on seedling mean root mass and total height. Seedlings grown with 20-20-20 plus 10-52-17 were significantly taller, had significantly smaller root systems, and were less sturdy than seedlings grown under the 20-8-20 fertilizer regime. The 20-8-20 fertilizer treatment appears to have resulted in some degree of height control and generally more desirable morphological characteristics.

4 SUMMARY AND IMPLEMENTATION

Ongoing reforestation research at RRRS will use the early results of this study to help define cost-effective northern latitude nursery cultural regimes for producing high performance seedlings. Germination temperatures will be 20°C over a 24-h day for the first 5 days, with the objective of speeding up the actual germination process and inducing crop uniformity. The remaining 23 days will be controlled at 20/11°C over a 12/12-h day/night to encourage control of early crop growth and to minimize associated heating costs.

The proposed germination regime will be tested in 1988 to assess further the effects on seedling morphology. The early results warrant pilot scale testing, but at this time the split germination temperature regime is not recommended for broad operational use.

When control of height growth is a critical factor in future studies at RRRS, no fertilizers will be incorporated in container mix, and a 20-8-20 grower formulation rather than a 20-20-20 Hi-Sol will be used throughout the season. It will be necessary to monitor tissue phosphorus levels in this low P regime (W. Gates, Pers. Comm., B.C. Forest Service, Silviculture Branch, Surrey, B.C. March 30, 1988). As well media pH will be regularly assessed because of the effect of pH on phosphorus availability.

In addition to the early nursery results of germination regimes and fertilizer treatments reported here, farm field tests of this material will begin in 1988[2]. Field performance from such trials are the ultimate criteria by which nursery cultural regimes developed at RRRS will be judged.

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[2] As of November 1988, no significant differences were measured in first field season height or diameter increment among the different germination treatments.

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